# Interconnection Evaluation Study Report

## 100 MW Wind Generation in Columbia County, Wisconsin
## MISO #G371 (#37921-01)

## Prepared for the Midwest ISO

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# 1. Executive Summary

This report contains the Interconnection Evaluation Study ("IES") for the Generator Interconnection Request ("GIR") MISO project #G371, MISO Queue #37921-01. The purpose of this study is to evaluate the impact of the addition of 100 MW wind generation in Columbia County, Wisconsin. The requested in-service date for this project is March 1, 2005.

Multiple connection configurations for G371 were considered, but only one configuration was studied. This preferred configuration connects G371 to the new Friesland 138 kV substation. The Friesland substation is being built to serve the needs of a new Ethanol plant and is located between the North Randolph and Hamilton Street substations. The bus at the Friesland substation will be extended to allow for the interconnection of G371. The one-line diagram of the existing system without the G371 connection is shown in Figure 1.1. The one-line diagram of the system with the addition of the G371 connection is shown in Figure 1.2.

The proposed G371 wind farm will have a single collection bus at a voltage level of 34.5 kV. A 34.5 kV cable and a 138/34.5 kV transformer will connect the wind farm collection bus to a new straight bus section added to the Friesland substation. The generation facility will have a 138 kV breaker on the high side of the generator step up transformer.

This study reviews the stability and thermal violations in the existing system and those due to G371 to determine what system upgrades would be required for the interconnection of G371. Short-circuit impacts due to G371 was not evaluated due to the fact that the induction generators typically contribute significant short-circuit current only within the first 1 ~ 1.5 cycles after a fault.

## Further Study

The next step in the GIR process is for the Generator to decide whether to proceed with a Facility Study. A Facility Study would investigate if additional VAR compensation at the generator facility will address voltage oscillations seen for various faults or if an operating restriction controlling the power factor of the wind farm will be the preferred solution. The Facility Study would also include a budgetary cost estimate for any ATC transmission system modifications that are required to resolve the identified impact problems.

## Required G371 Interconnection Equipment

An addition to the Friesland substation 138kV straight-bus is required to interconnect the G371 generation to the ATC transmission system. The Generator is responsible for all equipment on the G371 side of the Point of Interconnection to the ATC transmission system, including a high side disconnect switch, circuit breaker, GSU transformer and all necessary relaying.

## System Upgrades

Existing System Before G371

*Stability Related*

Analysis from the G366 and G368 System Impact Studies showed that G366 and G368 trip for various faults placed on the transmission system. Changes in the turbine ride-through characteristics for G366 and G368 could impact the transmission system prior to the addition of G371 and could require a re-evaluation of the system prior to the interconnection of G371 in the Facility Study.

*Breaker Duty Related*

The G371 wind farm does not aggravate the existing system. Therefore, no upgrades in this regard are required before the in-service date of G371.

Required Upgrades After G371

*Stability Related*

Voltage oscillations associated with the addition of G371 were found for various contingency scenarios. These oscillations may be corrected with either a generator operating restriction or with additional VAR compensation located at the wind farm. It was found that G371 can ride through primary faults at or near the Friesland substation. Any changes in the turbine ride-through characteristics for G366 and G368 may impact the transmission with the addition of G371 and could require a re-evaluation of G371 in a Facility Study.

While the generator is not required to ride through for all breaker failure contingencies, settings for selected breakers at North Randolph and Portage can be modified for the best possible operation to eliminate the tripping of the wind farm for some of these contingencies.

*Breaker Duty Related*

The G371 wind farm does not aggravate the existing system. Therefore, no upgrades in this regard are required after the in-service date of G371.

Proposed Upgrades After G371

*Thermal Overload Related*

For summer 2005 and winter 2005/2006 the addition of G371 did not create any additional overloads for single contingencies. For summer 2006, one single contingency produced an overload for the addition of G371. The facility overloaded due to the single contingency currently does not have a project identified. A Facility Study analysis or a Transmission Service Request Analysis must be performed to further evaluate these elements and the potential solutions. No voltage violations were identified for the addition of G371.

## Operation Restrictions

Operation restrictions on the G371 generation were identified due to thermal constraints for seven prior outage scenarios, a summary of which can be found in Table D.1 in the Appendix D. G371 may be required to operate at a power factor of 0.95 lagging (producing) to 1.0 unity to address voltage oscillations seen in the stability analysis.

**Figure 1.1 – One Line Diagram of the Existing System Before the Addition of G371**

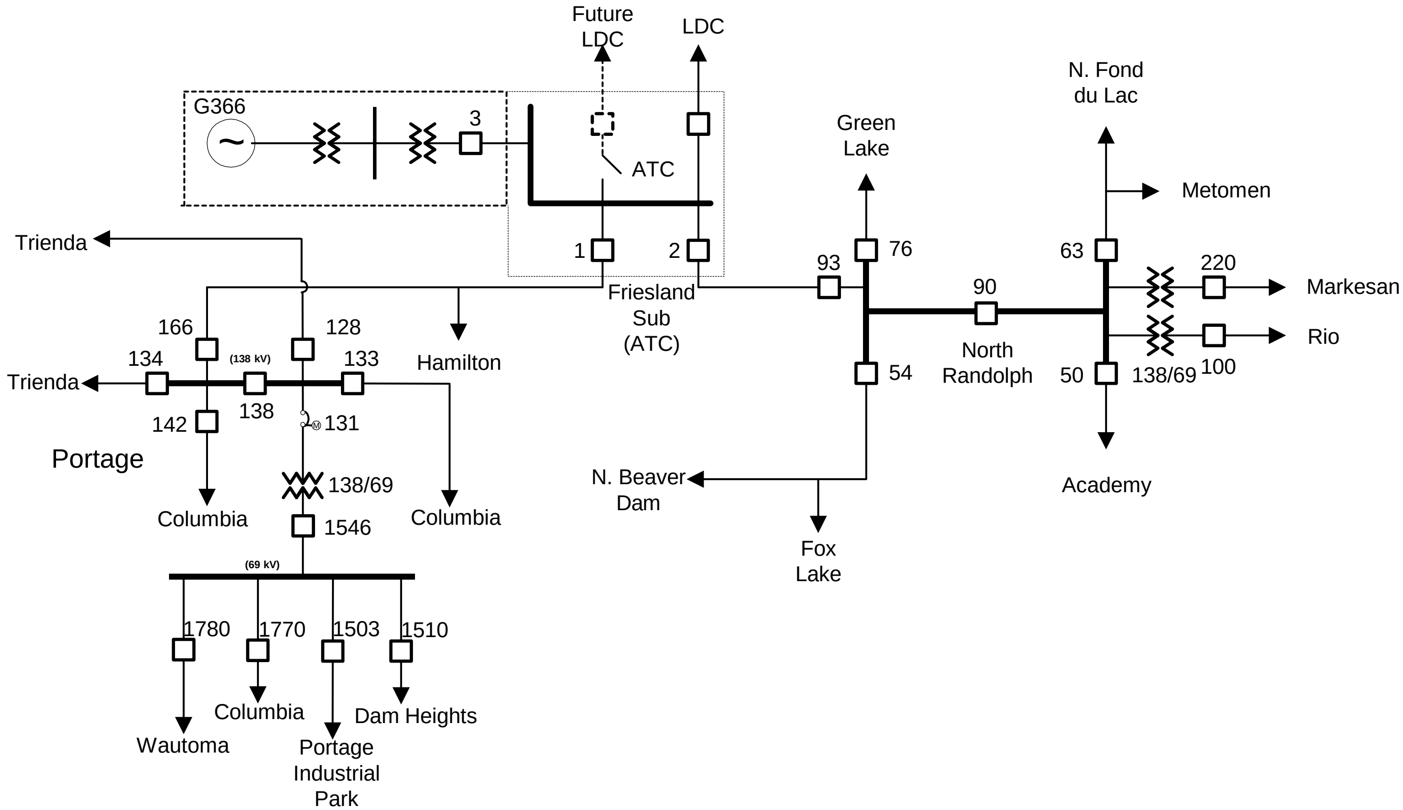
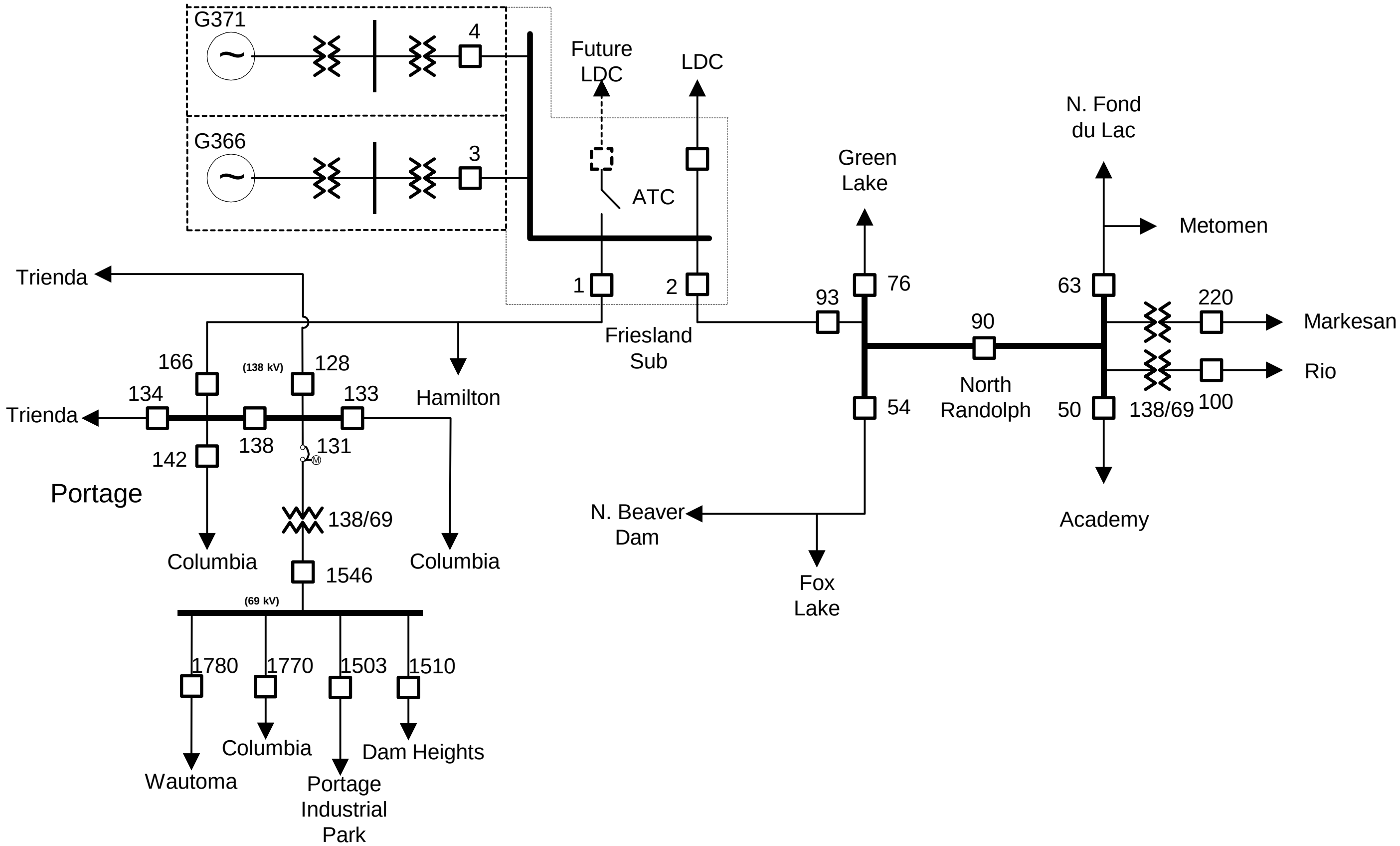


**Figure 1.2 – One Line Diagram of the System After the Addition of G371 (Preferred Connection)**



# 2. Criteria, Methodology and Assumptions

## 2.1 Study Criteria

All relevant MISO-adopted NERC Reliability Criteria and the ATC contingency criteria are to be met for both the stability analysis and the thermal analysis. Details of the stability and thermal analysis criteria applied in this study can be found in Appendix F.

## 2.2 Study Methodology

The results of this study are subject to change. The results are based on data provided by the Generator and other ATC system information that was available at the time the study was performed. If there are any significant changes in the generator and controls data, in earlier queue GIRs, in related Transmission Service Requests, or ATC transmission system development plans, then the results of this study may also change significantly. Therefore, this request is subject to restudy. The Generator is responsible for communicating any significant generation facility data changes in a timely fashion to ATC prior to commercial operation.

### 2.2.1 Competing Generator Requests

ATC determined in its sole judgment that two GIRs with an earlier queue position will impact the G371 study results. G366 and G368 are considered competing requests for the interconnection of this generator. G368 is not shown in the one-line diagrams in this report since it is located on the 138 kV line between South Fond du Lac and Butternut substations, beyond the area depicted in Figures 1.1 and 1.2.

Public information related to these GIR queues can be found via the MISO web site at http://oasis.midwestiso.org/documents/ATC/queue.html

### 2.2.2 Before and After Comparison Approach Employed in Stability Analysis

In the stability analysis performed for this study, to identify what impacts should be attributed to the addition of G371 interconnection; two system conditions were examined - "Before" the addition of G371 and "After" the addition of G371. Any violations of the stability study criteria identified in the "Before" state are defined to be existing system violations. Any new violations identified in the "After" state or violations identified in both "Before" and "After" states and are worse in the "After" state are to be attributed to the addition of G371. Only those existing system violations that are made worse by the G371 wind farm are deemed relevant to the G371 interconnection request and are documented in this report. Any other identified existing system violations that are not made worse by the G371 wind farm are deemed unrelated to the G371 interconnection request and are documented elsewhere as part of the internal ATC planning projects.

The results for the existing system before G371 was obtained from the G366 system impact study. Although G368 is listed as a competing request, it was later determined that the relative location and operating characteristics of G368 would have little effect on the results from the G366 Interconnection Evaluation Study. Therefore, the G366 Interconnection Evaluation Study provides an accurate representation of the transmission system prior to the addition of G371 for this Interconnection Evaluation Study. Any changes in the turbine ride-through characteristics for G366 and G368 may impact the transmission system prior to the addition of G371 and could require a re-evaluation of G371 in a Facility Study.

2.2.2 Linear Transfer Analysis and A.C. Load Flow Analysis Methods Employed in Thermal Overload and Steady-State Voltage Evaluations

The PSS/E AC Contingency Calculation (ACCC) tool (PSS/E, Version 28.0) program from Power Technologies, Inc (PTI) was used in this study to identify thermal overloads and voltage violations. Due to the fact that G366 and G368 go in-service after G371, three separate models were created to simulate the various in-service dates of G371 and the competing generators. Three seasons of operation were studied to account for the different in-service dates of the competing generators. Cases for 2005 summer, 2005/2006 winter, and 2006 summer were created with and without G371. Overload violations were identified using the models with and without G371 to determine the net impact that G371 caused on the elements with the overload violations. A distribution factor margin of 3% was used when comparing flows in the base cases with and without G371 for the analysis.

The models containing G371 were evaluated for bus voltages below ATC standard bus voltage levels of 0.90 per unit for single and double contingency events and 0.95 per unit for intact system before and after the addition of G371. Bus voltages that degrade more than 1% with the addition of G371 are reported in this thermal study.

2.2.3 Base Cases

In the stability analysis of this study, a 2005 50% summer peak load case was used. This base case was developed based on the NERC 2002 series MMWG (Multi-Regional Modeling Working Group) 2004 summer peak load and 2003 light load cases. A 2004 50% summer peak case was initially created and then modified by scaling the 2004 loads up by 3% and economically dispatching generation within the ATC territory to represent a 2005, 50% summer peak load profile.

In the thermal overload analysis of this study, MISO (Midwest Independent System Operator) monthly cases of July 2005, January 2006 and July 2006 were used. The MISO monthly cases are accessible through MISO Extranet.

## 2.3 Assumptions

2.3.1 Generation Facility Modeling

The G371 wind farm is modeled by a lumped representation in this study. It is modeled as a generator in the load flow case and represented by a user-written model in the dynamic simulations. This user-written model includes dynamic representations of the wind machines and the necessary voltage and frequency tripping algorithms. The wind turbine voltage ride-through capability is included in the modeling as shown in Appendix E.

# 3. Analysis Results

## 3.1 Stability Analysis Results

The stability analysis was performed using the Dynamics Simulation and Power Flow modules of the Power System Simulation/Engineering-28 (PSS/E, Version 28) program from Power Technologies, Inc (PTI). This program is accepted industry-wide for dynamic stability analysis.

A 2005 light load (50% summer peak) was evaluated in the stability analysis.

The stability criteria used in this study require that all machines modeled in the system must remain stable after a three-phase fault is cleared from any transmission element under the following conditions:

1) Fault cleared in primary time with an otherwise intact system
2) Fault cleared in primary clearing time with a pre-existing outage of any other transmission element.

The stability criteria also require that all machines remain stable for a fault cleared in delayed clearing time (i.e. breaker failure conditions) with an otherwise intact system. Wind turbines are exempt from this criterion, but must not aggravate system deficiencies.

Transient stability studies were performed to determine if the critical clearing times for all pertinent contingencies were less than the maximum expected clearing times. Any critical clearing times that were less than the actual clearing times would, therefore, be considered unacceptable.

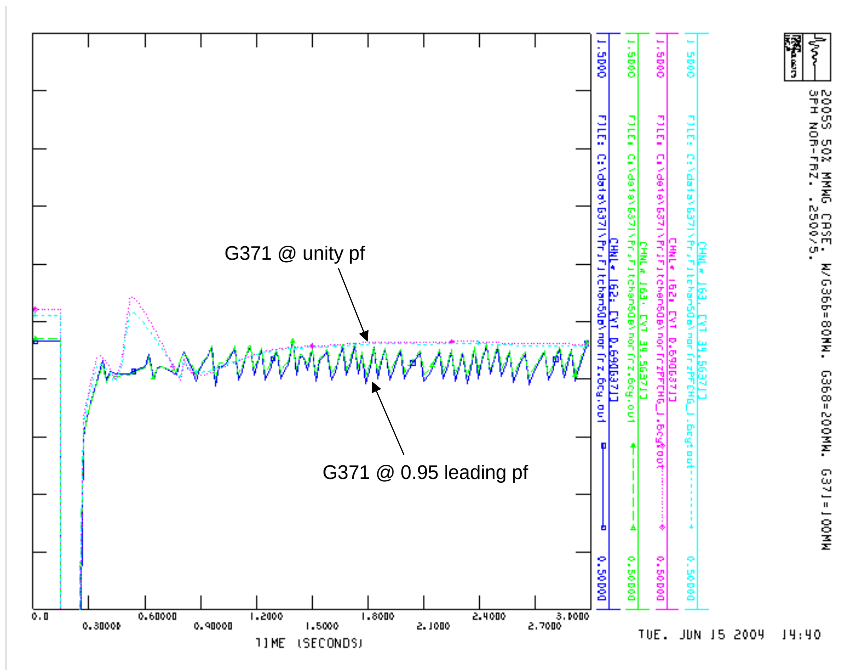
### 3.1.1 Results of Primary Fault Contingencies

<u>Before G371</u>
It was determined in the G366 system impact study that G366 is not capable of riding through a primary fault at the Friesland 138 kV bus with the existing ride–through characteristics supplied by this generator. The customer is required to supply improved ride-through capabilities for this generator for the G366 Facility Study. Any improvement to G366 may impact G371 and will be reviewed in the G371 Facility Study.

<u>After G371</u>
The primary contingency results are summarized in Table A.1 in Appendix A. Stability analysis did not identify any angular stability violations for any primary contingencies studied when the G371 generation is at its full capacity of 100 MW. No damping violations were found for any of the primary contingencies studied. However, G371 produced an unacceptable voltage oscillation for contingency #3 (Figure 3.1). An additional simulation was performed with G371 modeled at unity power factor (as seen at the Friesland 138 kV bus point of interconnection). This

simulation (Figure 3.1) demonstrates the potential need for G371 to operate at a power factor ranging from 0.95 lagging (producing VARS) to 1.0 unity. G371 will either have an operating restriction requiring the wind farm to operate at a power factor between 0.95 lagging to 1.0 unity or may be required to install additional compensation (For example, switched capacitors or a STATCOM) to eliminate the voltage oscillations. The customer should review this oscillatory behavior with the manufacturer to determine if this may solely be a modeling issue.

**Figure 3.1 – Oscillating Voltage Response of G371 for a Fault on the North Randolph – Friesland 138 kV Line.**




### 3.1.2 Results of Breaker Failure Contingencies

<u>Before G371</u>

It was determined in the G366 system impact study that G366 is not capable of riding through a most breaker failure faults with the existing ride–through characteristics supplied for this generator. The customer is required to supply improved ride-through capabilities for this generator for the G366 Facility Study. Any improvement to G366 may impact G371 and will be reviewed in the G371 Facility Study.

<u>After G371</u>

The breaker failure contingency results are summarized in Table A.2 in Appendix A. Several contingencies studied caused G366, G368 and G371 to trip off line prior the actual clearing time. In all of the cases evaluated, the addition of G371 did not cause existing system generators to go unstable prior to the actual clearing time. Currently, ATC does not require wind farms to correct all breaker failure deficiencies prior to commercial service. However, deficiencies that can be corrected with relay setting modifications or direct equipment replacement, may be considered to limit the number of contingencies that could cause the wind farm to trip off line. No damping violations were found for any of the breaker failure contingencies studied. Voltage oscillations were found for one breaker failure contingency. The Facility Study will determine if operating G371 at unity power factor can eliminate the oscillations, or if additional VAR compensation may be adequate.

### 3.1.3 Results of Prior Outage Contingencies

Before G371

It was determined in the G366 system impact study that G366 is not capable of riding through most primary faults, with a prior outage. The customer is required to supply improved ride-through capabilities for this generator for the G366 Facility Study. Any improvement to G366 may impact G371 and will be reviewed in the G371 Facility Study.

After G371

The prior outage contingencies evaluated and the study results are summarized in Table A.3 in Appendix A. Stability analysis did not identify any angular stability violations for any prior outage contingencies studied when the G371 generation is at its full capacity of 100 MW. No damping violations were found for any of the prior outage contingencies studied. However, voltage oscillations were found for several contingencies studied. The Facility Study will determine if operating G371 at unity power factor can eliminate the oscillations, or if additional VAR compensation may be adequate.

### 3.1.5 Recommended Solutions for the Wind Turbines

G371 is able to ride through all of the primary and prior outage contingencies studied. However, if G366 provides improved ride-through characteristics, the Facility Study will determine if a change in G366 performance will impact the performance of G371.

It was determined that the voltage oscillations observed for several contingencies may be able to be controlled by limiting G371's power factor range (0.95 lagging (producing VARS) - 1.0 unity). The Facility Study will determine if an operating restriction or a VAR compensation device is the best means of achieving this requirement.

Several breaker failure contingencies revealed that G366, G368 and G371 trip off line prior to the fault being cleared by the existing equipment. For the critical clearing times greater than 13.0 and less than 18.0 cycles, the Facility Study will determine what would need to be changed in order to keep the wind farms from tripping off line.

## 3.2 Short-Circuit Analysis Results

Short-circuit analysis was not performed due to the fact that the induction generators typically contribute significant short-circuit current only within the first 1 ~ 1.5 cycles after a fault. No system upgrades due to breaker duty are required prior to the interconnection of G371.

The maximum and minimum short-circuit duties at the G371 Point of Interconnection (POI) and the Thevenin equivalent impedances at the G371 POI are provided in Tables B.1 through B.3 in the Appendix B.

## 3.3 Thermal Analysis Results

The thermal overload analysis was performed using the AC Contingency Solution analysis tool within the PSS/E – Version 28.0 program from Power Technologies, Inc (PTI). This program is accepted industry-wide for thermal overload analysis.

The thermal analysis was performed using three MISO monthly base cases. A model was created to simulate conditions in July 2005, January 2006 and July 2006. The January 2006 model was initially a MISO January 2005 model created from the 2001 Series NERC/MMWG. Loads were scaled to expected Winter 2005/06 peak levels for the January 2006 case. All ATC projects projected to be completed and in-service by June 2005 were added to the January 2006 model. The July 2006 model was initially a MISO July 2004 model created from the 2002 Series NERC/MMWG. Loads were scaled to expected Summer 2006 peak levels and all ATC projects expected to be completed and in-service by June 2006 were added to the model. Since G371 does not have a transmission service request submitted at the time of the study, the 100MW G371 generation was delivered to the CE (75%) and NSP/Xcel (25%) control areas in this study. The G371 generation was assumed operating at 95% leading power factor.

Table C.1 through C.3 list the thermal overloads in which G371 contributes to the loading problem. One single contingency in Summer 2006 results in an overload due to the addition of G371. The addition of G371 does not cause any voltage violations.

# Appendix A

# Stability Analysis Results

## Notes:

1. All analysis performed with G371 operating at 0.95 leading (absorbing) power factor.
2. Table abbreviations: NOR – North Randolph, POR – Portage, GSS – Green Lake, NBD – North Beaver Dam, RIO – Rio Pumping Station, COL – Columbia, TRI – Trienda, NMA – North Madison., FRZ – Friesland, NFL – North Fond du Lac, ADY – Academy, HAM - Hamilton.
3. The fault is applied at the first named terminal of the faulted element unless otherwise noted. All faults modeled were 3-phase faults.
4. Calculated CCT = Critical Clearing Time (cycles). MECT = Actual Maximum Expected Clearing Time (cycles). Red cell indicates actual equipment clearing times that times that are inadequate.
5. All existing generators remained stable for faults applied to 18.0 cycles. See "Transient Problems" column for a list of wind generators tripping prior to the MECT.
6. N/A – Run not applicable.

### Table A.1 – Stability Analysis Results of Primary Fault Contingencies For the Expected 2005 System After the Addition of G371 Generation[1]

| Item | Faulted Facilities[2,3] | MECT[4] | Calculated CCT[4] | Transient Problems |
|---|---|---|---|---|
| 1 | FRZ – NOR 138kV | - | ≥10.0 | G366 tripped @ <6.0 |
| 2 | FRZ – POR 138kV | - | ≥10.0 | G366 tripped @ <6.0 |
| 3 | NOR – FRZ 138kV | 5.0 | ≥10.0 | G371 Voltage Oscillation Problem |
| 4 | NOR – GSS 138kV | 5.0 | ≥10.0 | G366 tripped @ 7.0 |
| 5 | NOR – NBD 138kV | 5.0 | ≥10.0 | G366 tripped @ 7.0 |
| 6 | NOR – NFL 138kV | 5.0 | ≥10.0 | G366 tripped @ 7.0 |
| 7 | NOR – RIO 69kV | 5.0 | ≥10.0 | None |
| 8 | POR – COL 138kV | 5.0 | ≥10.0 | None |
| 9 | POR – FRZ 138kV | 5.0 | ≥10.0 | None |
| 10 | POR – TRI 138kV | 5.0 | ≥10.0 | None |
| 11 | POR – COL 69kV | 5.0 | ≥10.0 | None |
| 12 | POR 138/69kV XFM | 5.0 | ≥10.0 | None |

### Table A.2 – Stability Analysis Results of Breaker Failure Contingencies For the Expected 2005 System After the Addition of G371 Generation[1]

| Item | Faulted Facilities | Failed Circuit Breaker | Element(s) Cleared In Breaker Failure | MECT | Calculated CCT | Transient Problems |
|---|---|---|---|---|---|---|
| 1 | FRZ – NOR 138kV | G366 3 | G366 1, 2 | 13.0 | ≥18.0[5] | G366, G371 tripped @ <13.0<br>G368 tripped @ 16.0 |
| 2 | FRZ – POR 138kV | G366 2 | G366 1, 3 | 13.0 | ≥18.0[5] | G366, G371 tripped @ <13.0<br>G368 tripped @ 16.0 |
| 3 | NOR – FRZ 138kV | NOR 93 | NOR 54, 76, 90 | 18.0 | ≥18.0[5] | G368 tripped @ 16.0<br>G371Voltage Oscillation Problem |
| 4 | NOR – GSS 138kV | NOR 76 | NOR 54, 90, 93 | 18.0 | ≥18.0[5] | G366, G371 tripped @ <13.0<br>G368 tripped @ 18.0 |
| 5 | NOR – NBD 138kV | NOR 54 | NOR 76, 90, 93 | 18.0 | ≥18.0[5] | G366, G371 tripped @ <13.0<br>G368 tripped @ 16.0 |
| 6 | NOR – RIO 69kV | NOR 102 | NOR 100, 220, 638 | 18.0 | ≥18.0[5] | None |
| 7 | POR – COL 138kV | POR 142 | POR 134, 138, 166 | 18.0 | ≥18.0[5] | G368, G371 tripped @ 17.0<br>G366 tripped @ 15.0 |
| 8 | POR – FRZ 138kV | POR 166 | POR 134, 138, 142 | 18.0 | ≥18.0[5] | G371 tripped @ 17.0<br>G368 tripped @ 14.0 |
| 9 | POR – TRI 138kV | POR 134 | POR 138, 142, 166 | 18.0 | ≥18.0[5] | G371 tripped @ 14.0<br>G368 tripped @ 17.0 |
| 10 | POR – COL 69kV | POR 1546 | POR 128, 133, 138 | 18.0 | ≥18.0[5] | None |

**Table A.3 – Stability Analysis Results of Prior Outage Contingencies For the Expected 2005 System After the Addition of G371 Generation[1]**

| Prior Outage | Item | Faulted Facilities | MECT | Calculated CCT | Transient Problems |
|---|---|---|---|---|---|
| COL – SFL 345kV | 1 | FRZ – NOR 138kV | - | ≥6.0 | G366 tripped |
| | 2 | FRZ – POR 138kV | - | ≥6.0 | G366 tripped |
| | 3 | NOR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 4 | NOR – GSS 138kV | 5.0 | ≥6.0 | None |
| | 5 | NOR – NBD 138kV | 5.0 | ≥6.0 | None |
| | 6 | POR – COL 138kV | 5.0 | ≥6.0 | None |
| | 7 | POR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 8 | POR – TRI 138kV | 5.0 | ≥6.0 | None |
| NOR – FRZ 138kV | 9 | FRZ – NOR 138kV | N/A | N/A | N/A |
| | 10 | FRZ – POR 138kV | N/A | N/A | N/A |
| | 11 | NOR – FRZ 138kV | N/A | N/A | N/A |
| | 12 | NOR – GSS 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 13 | NOR – NBD 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 14 | POR – COL 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 15 | POR – FRZ 138kV | N/A | N/A | N/A |
| | 16 | POR – TRI 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| NOR – GSS 138kV | 17 | FRZ – NOR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 18 | FRZ – POR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 19 | NOR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 20 | NOR – GSS 138kV | N/A | N/A | N/A |
| | 21 | NOR – NBD 138kV | 5.0 | ≥6.0 | None |
| | 22 | POR – COL 138kV | 5.0 | ≥6.0 | None |
| | 23 | POR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 24 | POR – TRI 138kV | 5.0 | ≥6.0 | None |
| POR – COL 138kV | 25 | FRZ – NOR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 26 | FRZ – POR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 27 | NOR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 28 | NOR – GSS 138kV | 5.0 | ≥6.0 | None |
| | 29 | NOR – NBD 138kV | 5.0 | ≥6.0 | None |
| | 30 | POR – COL 138kV | N/A | N/A | N/A |
| | 31 | POR – FRZ 138kV | 5.0 | ≥6.0 | None |
| | 32 | POR – TRI 138kV | 5.0 | ≥6.0 | None |
| POR – FRZ 138kV | 25 | FRZ – NOR 138kV | 5.0 | ≥6.0 | N/A |
| | 26 | FRZ – POR 138kV | 5.0 | ≥6.0 | N/A |
| | 27 | NOR – FRZ 138kV | 5.0 | ≥6.0 | N/A |
| | 28 | NOR – GSS 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 29 | NOR – NBD 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 30 | POR – COL 138kV | N/A | N/A | None |
| | 31 | POR – FRZ 138kV | 5.0 | ≥6.0 | N/A |
| | 32 | POR – TRI 138kV | 5.0 | ≥6.0 | None |

**Table A.3 Cont. – Stability Analysis Results of Prior Outage Contingencies For the Expected 2005 System After the Addition of G371 Generation[1]**

| Prior Outage | Item | Faulted Facilities | MECT | Calculated CCT | Transient problems |
|---|---|---|---|---|---|
| NOR – ADY 138kV | 25 | FRZ – NOR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 26 | FRZ – POR 138kV | 5.0 | ≥6.0 | G366 tripped |
| | 27 | NOR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 28 | NOR – GSS 138kV | 5.0 | ≥6.0 | None |
| | 29 | NOR – NBD 138kV | 5.0 | ≥6.0 | None |
| | 30 | POR – COL 138kV | N/A | N/A | None |
| | 31 | POR – FRZ 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |
| | 32 | POR – TRI 138kV | 5.0 | ≥6.0 | None |
| NOR – NFL 138kV | 33 | FRZ – NOR 138kV | N/A | N/A | G366 Tripped |
| | 34 | FRZ – POR 138kV | N/A | N/A | G366 Tripped |
| | 35 | NOR – FRZ 138kV | N/A | N/A | G371 Voltage Oscillation Problem |
| | 36 | NOR – GSS 138kV | 5.0 | ≥6.0 | None |
| | 37 | NOR – NBD 138kV | 5.0 | ≥6.0 | None |
| | 38 | POR – COL 138kV | 5.0 | ≥6.0 | None |
| | 39 | POR – FRZ 138kV | N/A | N/A | G371 Voltage Oscillation Problem |
| | 40 | POR – TRI 138kV | 5.0 | ≥6.0 | G371 Voltage Oscillation Problem |

## Appendix B

# Short Circuit Analysis

*Table B.1 – Maximum and Minimum Fault Duties*
*At the G371 Point of Interconnection without the Contribution from G371*

| **Maximum Fault Duty** | | **Minimum Fault Duty** | |
|---|---|---|---|
| **Single-phase** | **Three-Phase** | **Single-phase** | **Three-Phase** |
| 7200 Amps | 9900 Amps | 2530 Amps | 3950 Amps |

**Note:** Minimum fault duty was calculated with the 138kV line North Randolph – G366 out of service.

*Table B.2 – Thevenin Equivalent Impedances in Ohms in Intact System*
*At the G371 Point of Interconnection without the Contribution from G371*

| **Pos Seq.** | **Neg. Seq.** | **Zero Seq.** |
|---|---|---|
| 1.52 + j7.92 | 1.52 + j7.92 | 3.77 + j16.6 |

*Table B.3 – Thevenin Equivalent Impedances in Ohms*
*In the System without the 138kV Line North Randolph – G366*
*At the G371 Point of Interconnection without the Contribution from G371*

| **Pos Seq.** | **Neg. Seq.** | **Zero Seq.** |
|---|---|---|
| 3.08 + j19.9 | 3.08 + j19.9 | 13.0 + j52.7 |

## Appendix C

# Power Flow Analysis

*Table C.1 – Summer 2005 Thermal Overloads Identified*
*100 MW Generation Delivery from G371 to ALTE Control Area*
*100 MW Generation Delivery to CE/NSP*
*G368 Dispatched*

| **Limiting Element** | **Existing MVA Rating** | **Worst Contingency** | **MVA Flow without G371** | **MVA Flow with G371** | **Solution for Limiting Element** |
|---|---|---|---|---|---|
| Single Contingencies | | | | | |
| None | | | | | |
| Double Contingencies | | | | | |
| G371 – North Randolph 138 kV | 240 | Columbia-South Fond du Lac 345 kV & Rockdale – Cambridge Tap | 228 (95%) | 297 (124%) | No[1] |
| Roslin – Lakehead 69kV | 42 | Columbia-South Fond du Lac 345kV & North Randolph – G371 | 39 (94%) | 43 (103%) | Yes[2] |
| Portage – Lakehead 69 kV | 42 | Columbia-South Fond du Lac 345kV & North Randolph – G371 | 41 (99%) | 45 (107%) | Yes[2] |

Note: All ratings referenced in this table are summer emergency ratings.

1. There is no previously identified project by ATC to solve the loading problem on the G371-North Randolph 138 kV line. Current limitation for this line is the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.
2. The Line from Portage to Wautoma is scheduled to be rebuilt to a minimum of 72 MVA. The project is scheduled to begin 2004 and will take approximately 2 years to complete.

*Table C.2 – Winter 2005/2006 Thermal Overloads Identified*
*100 MW Generation Delivery from G371 to ALTE Control Area*
*100 MW Generation Delivery to CE/NSP*
*G366 and G368 Dispatched*

| Limiting Element | Existing MVA Rating | Worst Contingency | MVA Flow without G371 | MVA Flow with G371 | Solution for Limiting Element |
|---|---|---|---|---|---|
| Single Contingencies | | | | | |
| None | | | | | |
| Double Contingencies | | | | | |
| G371 – North Randolph 138 kV | 287 | Columbia-South Fond du Lac 345 kV & Rockdale-Cambridge Tap 138 kV | 305 (106%) | 321 (112%) | No[1] |
| North Fond du Lac – Aviation 138 kV | 262 | South Fond du Lac-Fitzgerald 345 kV & Edgewater-Cedarsauk 345 kV | 292 (111%) | 308 (118%) | No[2] |
| Progress – Aviation 138 kV | 262 | South Fond du Lac-Fitzgerald 345 kV & Edgewater-Cedarsauk 345 kV | 265 (101%) | 284 (108%) | No[3] |
| Auburn – Butternut 138 kV | 272 | South Fond du Lac-Fitzgerald 345 kV & Edgewater-Cedarsauk 345 kV | 272 (100%) | 282 (104%) | No[4] |

Note: All ratings referenced in this table are winter emergency ratings.

1. There is no previously identified project by ATC to solve the loading problem on the G371-North Randolph 138 kV line. Current limitation for this line is the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.
2. There is no previously identified project by ATC to solve the loading problem on the North Fond du Lac – Aviation 138 kV line. Current limitations for this line are substation CT's and the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.
3. There is no previously identified project by ATC to solve the loading problem on the Progress – Aviation 138 kV line. Current limitation for this line is the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.
4. There is no previously identified project by ATC to solve the loading problems on the Auburn – Butternut 138 kV line or the Butternut substation. Current limitation for this line is the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.

*Table C.2 – Summer 2006 Thermal Overloads Identified*
*100 MW Generation Delivery from G371 to ALTE Control Area*
*100 MW Generation Delivery to CE/NSP*
*G366 and G368 Dispatched*

| **Limiting Element** | **Existing MVA Rating** | **Worst Contingency** | **MVA Flow without G371** | **MVA Flow with G371** | **Solution for Limiting Element** |
|---|---|---|---|---|---|
| Single Contingencies | | | | | |
| G371 – North Randolph 138 kV | 240 | Cambridge Tap - Rockdale 138 kV | 211 (88%) | 276 (115%) | No[1] |
| Double Contingencies | | | | | |
| G371 – North Randolph 138 kV | 240 | Columbia-South Fond du Lac 345 kV & Rockdale-Cambridge Tap 138 kV | 278 (116%) | 348 (145%) | No[1] |
| Montello – Endeavor Tap 69 kV | 42 | Columbia-South Fond du Lac 345 kV & G371-North Randolph 138 kV | 39 (93%) | 43 (102%) | Yes[2] |
| Kilborn – ACEC Winnebago 69 69 kV | 48 | Columbia-South Fond du Lac 345 kV & G371-North Randolph 138 kV | 56 (117%) | 61 (127%) | No[3] |
| Portage - Lakehead 69 kV | 42 | Columbia-South Fond du Lac 345 kV & G371-North Randolph 138 kV | 43 (106%) | 48 (115%) | Yes[2] |
| Lakehead - Roselin 69 kV | 42 | Columbia-South Fond du Lac 345 kV & G371-North Randolph 138 kV | 43 (102%) | 47 (111%) | Yes[2] |
| Roselin - Endeavor Tap 69 kV | 42 | Columbia-South Fond du Lac 345 kV & G371-North Randolph 138 kV | 41 (97%) | 45 (106%) | Yes[2] |
| Ripon – Northwest Ripon Tap 69 kV | 54 | Fitzgerald 345 kV Transformer Fault | 53 (99%) | 57 (105%) | No[4] |

Note: All ratings referenced in this table are summer emergency ratings.

1. There is no previously identified project by ATC to solve the loading problem on the G371-North Randolph 138 kV line. Current limitation for this line is the line conductor. G371 would likely be required to back down during prior outage events involving one of these two transmission elements. For the single contingency violation, G371 may be granted partial service up to the limit shown. Increasing the operating temperature of the line conductor would require further investigation by ATC Design Engineering.
2. The Line from Portage to Wautoma is scheduled to be rebuilt to a minimum of 72 MVA. The project is scheduled to begin 2004 and will take approximately 2 years to complete.
3. There is no previously identified project by ATC to solve the loading problem on the Kilborn – Winnebago 69 kV line. The line conductor operating temperature can possibly be increased to achieve the necessary rating, or an operating restriction could be placed on G371 during prior outage events involving one of these two transmission elements. Increasing the operating temperature of the line conductor or replacing substation equipment would require further investigation by ATC Design Engineering.
4. There is no previously identified project by ATC to solve the loading problem on the Ripon – Northwest Ripon 69 kV line. Substation relays would need to be upgraded to allow a higher operating limit of the line, or an operating restriction could be placed on G371 during prior outage events involving one of these two transmission elements. Further investigation by ATC Design Engineering is required to determine the complete scope of the project.

## Appendix D

# Summary of Operation Restrictions

*Table D.1 – Identified Operation Restrictions on the G371 Generation Under Prior Outage Scenarios*

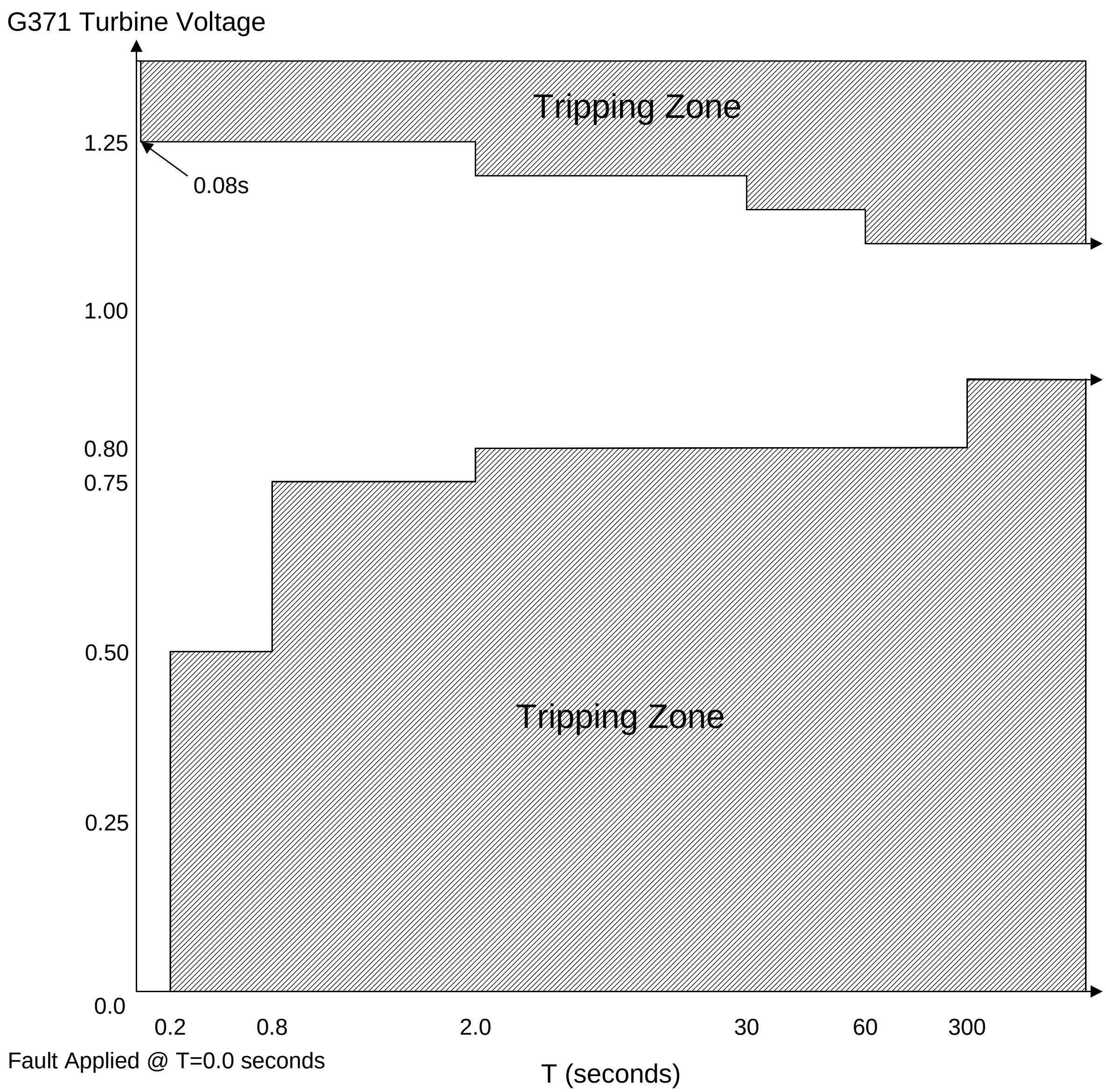
| **Prior Outage** | **G371 Max Allowable Output** | **Worst Next Contingency** | **Limiting Element** | **MVA Rating** | **Reason** | **Season** |
|---|---|---|---|---|---|---|
| Columbia – South Fond du Lac 345 kV Circuit #1 | 17.2 MW | Rockdale – Cambridge Tap 138 kV Circuit #1 | G371 – North Randolph 138 kV Circuit #1 | 240 | Thermal | Summer 2005[1] |
| North Randolph – G371 138 kV Circuit #1 | 12.5 MW | Columbia – South Fond du Lac 345 kV Circuit #1 | Portage – Lakehead 69 kV Circuit #1 | 42 | Thermal | Summer 2005[2] |
| Columbia – South Fond du Lac 345 kV Circuit #1 | 0.0 MW | Rockdale – Cambridge Tap 138 kV Circuit #1 | G371 – North Randolph 138 kV Circuit #1 | 287 | Thermal | Winter 2005/2006[1] |
| South Fond du Lac – Fitzgerald 345 kV Circuit #1 | 0.0 MW | Edgewater – Cedarsauk 345 kV Circuit #1 | North Fond du Lac – Aviation 138 kV Circuit #1 | 262 | Thermal | Winter 2005/2006[3] |
| Columbia – South Fond du Lac 345 kV Circuit #1 | 0.0 MW | Rockdale – Cambridge Tap 138 kV Circuit #1 | North Randolph – G371 138 kV Circuit #1 | 240 | Thermal | Summer 2006[1] |
| North Randolph – G371 138 kV Circuit #1 | 0.0 MW | Columbia – South Fond du Lac 345 kV Circuit #1 | Kilborn – ACEC Winnebago 69 kV | 48 | Thermal | Summer 2006[4] |
| Fitzgerald – South Fond du Lac 345 kV Circuit #1 | 0.0 MW | Fitzgerald – North Appleton 345 kV Circuit #1 | Ripon – Northwest Ripon Tap 69 kV | 54 | Thermal | Summer 2006[5] |

1. There is currently no project assigned for the overload of G371 to North Randolph 138 kV line. A rebuild of the line will be necessary.
2. The Line from Portage to Wautoma is scheduled to be rebuilt to a minimum of 72 MVA. The project is scheduled to begin 2004 and will take approximately 2 years to complete.
3. There is no previously identified project by ATC to solve the loading problem on the North Fond du Lac – Aviation 138 kV line. Current limitations for this line are substation CT’s and the line conductor.
4. There is no previously identified project by ATC to solve the loading problem on the Kilborn – Winnebago 69 kV line. The line conductor operating temperature can possibly be increased to achieve the necessary rating, or an operating restriction could be placed on G371 during prior outage events involving one of these two transmission elements.
5. There is no previously identified project by ATC to solve the loading problem on the Ripon – Northwest Ripon 69 kV line. Substation relays would need to be upgraded to allow a higher operating limit of the line, or an operating restriction could be placed on G371 during prior outage events involving one of these two transmission elements.

## Appendix E

# Proposed Fault Ride-Through Characteristics For G371 Wind Turbines

**Figure E.1 – Proposed Fault Ride-Through Characteristics Related to Voltage Tripping of G371 Wind Turbines**



# Appendix F

# Study Criteria

## Study Criteria

F.1 Contingencies

For stability analysis, a set of branches in the vicinity of the generator/power plant of concern is selected as contingencies, based on engineering judgment. Fault analysis is performed for the following three categories of contingency conditions:

1. Fault cleared in primary time with an otherwise intact system.
2. Fault cleared in delayed clearing time (i.e. breaker failure conditions) with an otherwise intact system.
3. Fault cleared in primary clearing time with a pre-existing outage of any other transmission element.

For the power flow analysis, the contingencies include the normal (intact) system configuration, standard N-1 contingencies and multiple contingencies that ATC has determined to be significant.

F.2 Monitored Elements

For power flow analysis, load carrying elements of voltage level above 69kV in the ATC areas – Alliant East Control Area, Wisconsin Electric Power Co. Control area, Wisconsin Public Service Corp Control Area and Upper Peninsula Power Co. Control Area were monitored in this Study. Flowgates in MISO footprint are also monitored, the results of which can be referenced by MISO.

F.3 Thermal Loading Criteria

For the normal (intact) system conditions, the loading of all transmission system elements with distribution factors greater than 0.05 must not exceed 95% of the summer normal rating (Rate A). For contingency system conditions, the loading of all transmission system elements with distribution factors greater than 0.03 must not exceed 95% of the summer emergency rating (Rate B).

F.4 Stability Criteria

Critical Clearing Time (CCT) is a period relative to the start of a fault, within which all generators in the system remain stable (synchronized). CCT is obtained from simulation. Maximum Expected Clearing Time (MECT) determines a period of time that is needed to clear a fault using the existing system facilities. MECT is dictated by the existing system facilities. In any contingency, if the computed CCT is less than the MECT plus a margin determined by ATC (1.0 cycle in This Study), it is considered an unstable situation and is unacceptable. Otherwise, it is considered acceptable stability performance.

In the context of stability analysis, voltages of all transmission system buses must recover to be at least 70% of the nominal system voltages immediately after the fault removal and 80% of the nominal system voltages in 0.5 second after fault removal.